Road maintenance, road decommissioning, and stream crossing upgrades

Road Upgrading, Decommissioning and Maintenance — Estimating Costs on Small and Large Scales

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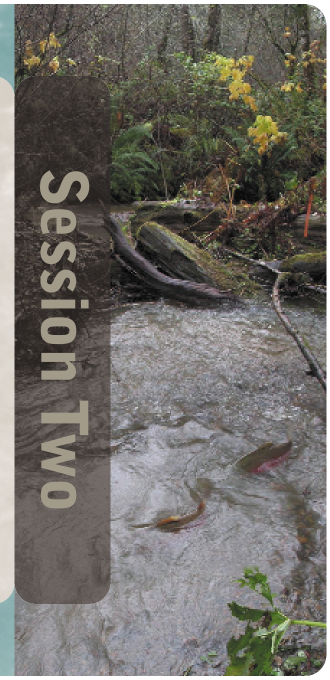

ABSTRACT

One of the most important threats to the health of stream systems is sediment delivery due to anthropogenic erosion. Road networks are often one of the most important sediment sources, so it is vital to the health of the watershed that they be maintained in good condition or decommissioned when no longer useful. This paper presents a detailed look at the process of planning and carrying out road upgrading, decommissioning and maintenance projects. The emphasis is on cost estimation; especially the ways that standardized data collection can facilitate the development of accurate estimates. Also included is a discussion of the ways in which cost estimation changes depending on the scale of the project, the type of use of the road (seasonal or year round, public or private), and whether a single road or an entire road network in a watershed is slated for treatment.

INTRODUCTION

Before considering the details of road repair work, it is important to understand the proposed project from a geologic perspective. More specifically, knowledge of the erosion and sedimentation history of an area, and the relative magnitude of various sediment sources, is necessary to properly evaluate the need and potential benefit of road work. Not everything that goes on in the watershed, even on the road systems, affects aquatic resources. It is critically important when deciding how much effort it will take to upgrade or decommission a road that care is taken to spend the money wisely and only on work that will have a beneficial impact on the aquatic system.

Road repair work is a broad category that encompasses many different types of improvements to forest road systems. These changes may, for example, improve access along the road, as when cut bank slides that have covered the roadbed are removed. However, road repair work does not always have an impact on aquatic resources. Hill slope failures, cut bank failures, gullies and surface erosion are not always connected with the stream channels, and so are not delivering sediment into the streams. Although road repair is something that landowners want to see completed, the work can be very expensive. When improving habitat for fish or aquatic resources is the top priority, it is important that only a limited amount of money be spent on repairs that do little to improve or protect the aquatic system. This requires a clear separation of typical road maintenance and upgrading work (designed to improve the transportation system) from those upgrading and decommissioning activities that are focused on reducing the magnitude or threat of sediment delivery to streams (Weaver and Hagans, 1999; Harr and Nichols, 1993; Weaver and Hagans, 1996).

In order to ensure that the work benefits fish, it is important to evaluate all potential projects by measuring or evaluating the effect the road is having on erosion and sedimentation into the streams in the area. This entails looking specifically at three elements of road systems, including stream crossings, potential road-related landslides and road surface drainage. Sediment can be generated and delivered from these locations in response to episodic storm events as well as from chronic erosion during normal runoff events. It is important to evaluate the susceptibility of stream crossings and potential landslides to failure and sediment delivery. Likewise, it is important to measure the connectivity of road surface drainage with streams, so that treatments can be designed to disconnect them, and thereby greatly reduce or effectively eliminate the movement of fine sediment and water off the road system and into streams.

It is important when conducting erosion inventory assessments on road systems that recommendations for treatments be very specific and be focused only on those features that would otherwise deliver sediment to a stream or other protected resource. There is typically only a limited amount of money available for treating road systems. For example, it does not make sense to upgrade an entire road system if only 20% of the money could be spent to stop most of the ongoing or future sedimentation caused by that road system. A virtually limitless amount of money could be poured into upgrading and decommissioning roads, but with limited funds, it is crucial to focus only on work that will directly protect or improve aquatic resources.

DIAGNOSING AND TREATING PROBLEMS ON ROADS

Road System Erosion

The four main erosion processes on road systems are surface erosion, gully erosion, mass erosion and channel erosion. Each process produces sediment, and a certain amount of this sediment may end up in streams. Usually, a lot more sediment is produced by the road system than is actually delivered to the streams. The key, then, in performing road system assessments is to define the scope or magnitude of road work to reduce sediment delivery to stream channels and to distinguish between sediment production (erosion) and sediment delivery (yield) to stream channels. Improving or protecting stream habitat requires preventing sediment delivery, but not necessarily controlling or preventing all erosion in the system.

Road-related problems fall into two categories. The first is chronic erosion and the second is episodic erosion, which is storm-related. Chronic erosion produces fine sediment every year, every time there is surface runoff, whether there are severe storms or not. Chronic surface erosion delivers fine sediment to streams wherever road drainage is discharged to a channel. Episodic erosion can be divided into mass soil movement and fluvial erosion. Fluvial erosion is mostly due to stream crossing washouts and gullies created by either stream diversions or hill slope gullies below ditch relief culverts along roads. Road-related mass soil movement that

Table 1. Sources and magnitude of road-related sediment delivery in selected Northern California watersheds[1]

Site location	Process	Sediment delivery for road-related erosion sites: Delivery range for sites (%)	(yds^3)	Average delivery (yds^3)	Percent of road-related sediment delivery (range)[2]
1. Chronic surface erosion from bare soil areas (road surfaces, ditches and cutbanks)[3]	Surface erosion	75–100%	NA	NA	15%–85%
2. Road-related landslide erosion	Mass wasting				15%–80%
Fill slope failures		5–100%	5–2,500	220	
Landing failures		5–100%	5–2,000	385	
Cut bank failures		50–100%	10–150	80	
Hillslope landslides[4]		25–100%	10–10,000	3,500	
3. Stream crossing erosion	Fluvial erosion				35%–80%
Stream crossing washouts		100%	5–3,000	225	
Stream diversions (gullies)		80–100%	5–2,800	400	

1- Data based on inventories of Salmon Creek and Rowdy Creek road systems; sediment delivery from stream diversions based on data from Jordan Creek (lower Eel River).

2- Typically, watersheds with geologies like Salmon Creek and Rowdy Creek are dominated by fluvial processes, where road-related fluvial erosion (washouts and gullying at stream crossings) is expected to account for up to 85% of future sediment delivery. Road-related mass wasting is comparatively less in the watersheds. In steep, potential unstable watersheds on the north coast, such as those of the lower Eel River and the Mattole River, mass wasting may account for up to 65% of future road-related sediment delivery. In these watersheds, fluvial processes are relatively less important.

3- Sediment delivery from road-related surface erosion occurs where the road is hydrologically connected to the stream system. Delivery volumes are based on contributing length of road reach, use levels, surface erosion rates and duration of analysis. Delivery is based only on connected road reaches. Does not include surface erosion from non-road sources. Road erosion inventories reveal that many watersheds in central and north-central California, and in the Sierra Nevada mountains of eastern California, are dominated by surface erosion and fine sediment delivery.

4- Small to large hillslope slides triggered by road cuts, road fills or by altered hydrology (diversion or discharge).

results in sediment delivery to streams usually comes from fill-slope failures, failures from crossings of steep headwall swales, and occasionally from large cut-bank failures that go over the road and into a stream channel. Table 1 provides statistics on the relative volumetric importance of the different types of erosion on sediment delivery to streams in a variety of inventoried watersheds. As is clear from the table, the relative and absolute contribution of road-related sediment to stream channels can vary dramatically from one watershed to the next, and across the landscape from region to region.

Chronic Erosion

Chronic erosion from road surfaces is highly related to traffic use on the road, as well as the characteristics of the road surface. It is important to emphasize that the volume of chronic erosion that is occurring is less important than how much of the eroded sediment is actually being delivered to streams. For example, for one large landowner on the North Coast of California, erosion inventories were conducted for a variety of sediment sources, including, chronic surface erosion, road-related landslides, and fluvial and stream crossing erosion. The results of the erosion inventories were then compared to the measured volume of sediment that was actually delivered to stream systems. The findings indicated a wide variability in the percentages of sediment that finally made it into streams compared to the sediment that was eroded (See column 6, Table 1).

With respect to chronic surface erosion, fine sediment delivery in a watershed is partially controlled by the amount of the road system that is actually connected to the stream network. In many North Coast watersheds, less than 5% to 15% percent of the road is hydrologically connected to the stream system through inboard ditches or through hill slope gullies below ditch relief culverts. As a result, only that small percentage of the road is actually delivering sediment into the stream system (Table 1). In some other inventoried watersheds, up to 85% of the road network has been documented as being hydrologically connected to streams. In these watersheds, depending on erosion rates, fine sediment delivery from road surface erosion can overwhelm other road-related sediment sources.

This means that it is not necessary to treat the whole road in order to prevent stream sedimentation. Only the segments of road that are delivering sediment and that are hydrologically connected to the stream system need to be treated. This limits the numbers of and types of road treatments that need to be considered. Important treatments include installing or upgrading culverts, waterbars and rolling dips, and outsloping roads currently in use.

Episodic Erosion: Road-Related Landslide Erosion

Sediment deliveries for road-related landslides (usually fill slope failures) range from 5% to 100% of an individual landslide (Table 1), though in many cases the landslides do not deliver any sediment at all (0% delivery). Most of the landslides that occurred on roads in the assessment areas did not go into the stream channels, though they may have moved down the hillside and deposited sediment on a road, a terrace or a slope. It is important to distinguish between those that are delivering sediment and those that are not. The priority is to identify and treat the road-related landslides that deliver (or could deliver) sediment to a stream channel, and to not spend limited resources on landslides that do not impact or threaten aquatic resources.

Episodic Erosion: Stream Crossing Erosion

Virtually 100% of the sediment produced by every stream crossing that washes out ends up in a stream channel (Table 1). Because a stream crossing is by definition "crossing a valley with a channel that has a definable bed and bank, and shows evidence of periodic sediment transport," any erosion at this type of site will enter the stream.

When culverts plug and water flows down the road and across the hillside, in a process known as stream diversion, those gullies are usually well connected to the stream system. Based on recent watershed inventories, any time there is culvert failure at stream diversions, 80–100% of the sediment that is eroded from those gullies will be delivered to a stream (Table 1). Stream diversions can create large gullies and large volumes of eroded sediment that are efficiently delivered to streams (Weaver *et al.* 1995). Stream diversions onto steep hillslopes can also cause landslides and debris flows that produce potentially huge volumes of sediment delivery.

The critical thing to remember is that not all stream crossings are the same and not all hillslope gullies are the same. Each has different degrees of delivery to the stream channel. The bottom line is that erosion inventories and road assessments must be done on the ground, and not

Table 2. Summary road erosion inventory and sediment yield data for selected, inventoried watersheds in Oregon and Northern California

Watershed	River basin	Watershed area (mi^2)	Road length (mi)	Road density (mi/mi^2)	Future yield (yds^3)	Unit yield (yds^3/mi)
Shaw Creek	Eel River, CA	4	18	4.5	9,200	511
Jordan Creek	Eel River, CA	5	34	7.1	94,140	2,769
Bear Creek	Eel River, CA	8	39	4.9	131,605	3,375
McGarvey Ck.	Klamath River, CA	9	68	7.8	164,800	2,441
Pine Creek	Klamath River, CA	21	104	5.0	45,400	437
Elk River	Humboldt Bay, CA	22	133	5.9	88,090	662
Tish Tang Ck.	Trinity River, CA	31	74	2.4	17,100	231
Dumont Ck.	S. Umpqua R., OR	31	114	3.6	12,020	106
Mill Creek	Trinity River, CA	50	177	3.5	137,200	775
New River	Trinity River, CA	277	175	2.0	32,400	185
Totals		**460**	**936**	**2.0**	**731,958**	**782**

remotely, in order to accurately identify the risk and potential volume of future stream crossing erosion and sediment delivery. The most valuable assessment is on-the-ground, where the individual characteristics of each existing and potential sediment source can be identified.

Table 2 shows the results of field inventories of over 900 miles of forest and ranch road in ten different watersheds. Column 6 lists the predicted future yield from road-related sediment sources including potential fill-slope failures (fills with visible cracks and scarps), stream crossings that are prone to partial or complete wash out, or diversion, and from other sediment sources including gullies developed from road surface runoff. The future unit sediment delivery ranged from 100 to over 3,000 cubic yards per mile.

It is important not only to identify how much sediment is being delivered to the streams, but also to focus attention on the watersheds where there is critical habitat to protect. Biological considerations must also be taken into account when prioritizing road work that is aimed at protecting or restoring channel conditions and habitat. Some streams may not be worth improving, especially if there is very little likelihood fish will return once the habitat has been restored. Large amounts of money could be spent without achieving much success for the targeted fish species. In contrast, streams that are experiencing only low sedimentation rates and still have healthy populations may be well worth the effort, because small amounts of money may stop future anthropogenic sedimentation entirely.

Erosion/Sediment-Source Inventories

There are several different types of sediment-source inventories. The bottom line in determining the cost of either upgrading or decommissioning road systems is the ability to have an adequate on-the-ground inventory. In the past, erosion inventories have typically been "backward-looking," where people have walked the roads looking for voids or "holes" where erosion has occurred. This is the classic kind of study conducted by geologists for erosion inventories of major road systems and for sediment budget studies. About 95% of the literature documents erosion events that have already happened on roads, but this does little to provide significant insight into the locations and magnitudes of future erosion and sedimentation. Similarly, such studies do little to identify where monies might be best spent to control or prevent future erosion and sediment delivery.

A "forward-looking" or "predictive" inventory generates the information needed to develop costs for either upgrading or decommissioning roads, and for "turning off" or preventing existing or future sediment sources, respectively. The development of a predictive inventory requires more subtlety in the inventory process. In this case, the goal is to predict the location and evaluate the potential magnitude of erosion events that have not yet happened. This means trying to determine the likelihood that a slope is going to fail or a stream crossing is going to wash out, and what the volume and magnitude of the potential failure will be. This type of inventory requires more professional judgment. It is, however, not all that difficult when standardized techniques and protocols have been developed and are adhered to in the field.

Over the last 10 years, we have trained approximately 20 commercial salmon fishermen out of work in Northern California, and a number of scientists and physical science technicians, to do predictive road inventories and erosion assessments. Many are working full time now under grants administered by the California Department of Fish and Game and other funding agencies to inventory private lands. The inventories are being done on industrial and non-industrial forest lands, ranch lands, rural subdivisions, agricultural lands, and on public road systems throughout Northern California. The most significant prerequisites include the ability to "read" the landscape and the geomorphic/hydrologic processes that occur along roads, understanding of how the design and construction methods of a road can influence natural processes, training in standardized erosion inventory protocols and treatment prescriptions, and the necessary tools and equipment to complete the job.

Predictive inventories can occur at three different levels: a screening-level assessment, a reconnaissance-level assessment, and a fully quantitative assessment. These levels are summarized in Table 3. To complete a prescriptive on-the-ground site-by-site analysis of the road system and develop a viable plan of action for erosion prevention and erosion control, a quantitative assessment of the road system is necessary. It is important that all roads in a watershed (i.e. currently active, as well as abandoned roads) be included in an assessment. This allows for a more complete understanding of the current and potential risk of anthropogenic sediment production in the watershed.

The screening-level assessment makes it possible to categorize watersheds or large basins, to determine how much of the landscape is in sensitive terrain, what the road densities are in each of those terrain types, and what likely costs are associated with treating the roads in each of those different land categories. For a screening-level assessment, we use remote analysis via maps, existing data and Geographic Information System (GIS) techniques. We thereby obtain a screening-level tool that enables the development of generic cost estimates with low to moderate confidence that the work can be completed for that amount of money. At this level, there is

Table 3. Road sediment source inventory and assessment methods (PWA, 2000)

Assessment Type	Method	What you get	What you don't get
Screening level	Remote analysis employing maps, existing data and GIS analysis techniques employing management and landscape factors	Screening level tool to relatively rank roads in a watershed for their potential for sediment delivery. Generic, low to moderate confidence costs could be developed based on extrapolation of costs for roads in similar terrain, geology and geomorphic settings.	No site-specific location or quantification of potential sediment sources or development of treatment prescriptions or costs.
Reconnaissance level	Field reconnaissance survey of high priority roads	Ground verified inventory of obvious sites and suspect locations on high priority roads. Classification of estimated future yield in volume classes. Documents the frequency and general magnitude of the "threat." Costs can be estimated generically, with moderate confidence, by employing averages based on data from similar roads with similar site frequencies in comparable similar settings.	Not all roads are included in the survey. No treatment prescriptions, quantitative sediment delivery measurements or cost-effectiveness analyses are performed.
Quantitative	Field inventory of future sediment sources from all roads, or selected roads, in the watershed	Identification and quantification of potential sources of sediment delivery along all roads. Volumes, probabilities and a variety of road site data for crossings, fills and road drainage. High confidences cost estimates are developed based on physical measurements and evaluation of treatment sites.	Development of specific risk reduction plan, with prescriptions, costs, and cost-effectiveness analysis is not required but is generally undertaken.

no site-specific quantification of potential sediment sources or actual prescription of site-by-site costs or treatments.

Once the screening-level assessment is complete, the reconnaissance-level assessment requires going to the highest priority areas — those areas most likely to be generating sediment and delivering it to streams from the road systems — and doing walk-through surveys of the roads quickly. In these surveys, we identify stream crossings and categorize them by volume. The volume categories might be, for example, 0 to 50 cubic yards, 50 to 200 cubic yards, 200 to 500 cubic yards and larger than 500 cubic yards. This tally gives some idea of the frequency and sizes of all the sediment sources along the road. Generic cost estimates can then be made based on the tally. A reconnaissance-level assessment does not provide actual treatment prescriptions or quantitative sediment delivery measurements. As a result, it is impossible to produce a cost-effectiveness analysis at this level (Weaver and Sonnevil, 1984). Specific measurements of the potential sediment volumes delivered to a stream channel are supplied by the quantitative assessment.

The quantitative assessments that we are currently doing are part of an ongoing watershed restoration program in Northern California that are funded primarily by the California Department of Fish and Game (CDFG), but also being matched or partially funded by landowners and other state and federal granting agencies with interest in water quality. In excess of $20 million dollars a year are being applied to quantitative assessments and implementation projects for upgrading and decommissioning roads, including a full inventory of future sediment sources along road systems in the affected watersheds. The CDFG Fishery Restoration Grant Program is focused on watershed-wide work. For a 30 square mile watershed, for example, there might be an assessment budget of $125,000 to $175,000, depending on the road density in the basin. This is to be spent on the complete identification and quantification of potential sediment sources, as well as development of prescriptive measures and associated costs elements to correct or treat each existing or potential sediment source. It takes 10 to 30 minutes in the field at each individual site of future sediment delivery to collect pertinent inventory information and to develop the recommended treatment for that site. This assessment includes everything from quantifying the future sediment delivery (assuming no erosion prevention treatment was to be applied) to determining which types of heavy equipment will be required at that work site. After completing all three levels of assessment, the final product consists of a specific risk reduction plan (including treatment prescriptions, needed materials, equipment and labor), a budget and a cost-effectiveness analysis. Chapter 10, in the CDFG Salmonid Restoration Manual (1998), discusses in detail all the elements of a fully quantitative analysis.

Road Treatment

There are really only two choices for treating roads that have been determined to be existing or potential sediment sources. Both treatment types are generally referred to as "storm-proofing" (Pacific Watershed Associates, 1994; Weaver and Hagans, 1999). Either the road can be upgraded and maintained, or it can be decommissioned, either temporarily or permanently. In the past there would have been a third option: walking away from the problem and letting the road "return to nature". Most forest roads on the North Coast were historically in the walk-away category at some time during their lives. Built 30–40 years ago, they were used to access an area for timber harvest, and were simply left alone when they were no longer needed. Management practices have changed since then, and walking away from roads that are current or potential sediment sources is no longer considered a viable choice.

The Storm-Proofing Process

The storm-proofing process involves five different steps, described in Figure 1. First is *problem identification* through inventory field assessment, the details of which were discussed above. The next is *problem quantification*, which means determining how much sediment volume will be delivered to the stream if nothing is done. This information impacts cost-effectiveness. Thus, it does not make sense to do storm-proofing work where a lot of money will bring very little return benefit. It is important to be able to compare the future sediment production and delivery at each site in order to eventually prioritize them for treatment.

Figure 1. Five-step process for storm-proofing forest roads

1. Problem identification (through inventory and assessment)
2. Problem quantification (determination of future yield in the absence of treatment)
3. Prescription development (both heavy equipment and labor-intensive methods)
4. Cost-effectiveness evaluation and prioritization of sites proposed for treatment
5. Implementation of upgrading or decommissioning treatments

The third step is the *development of a prescription* for road treatment, which includes both heavy equipment and labor-intensive measures for erosion prevention or erosion control. The fourth step is performing a *cost-effectiveness evaluation and prioritizing the sites* to be treated. The cost-effectiveness evaluation will help make it possible to spend money where it will yield the greatest return for the investment. Cost-effectiveness is determined for a site or a group of sites by calculating the total cost of performing the work and dividing that figure by the volume of sediment that is expected to be prevented from delivery to a stream. Note: this is not the volume of earth which must be excavated and/or moved to accomplish the recommended treatments. Once the sites have been prioritized, the fifth and final step in the storm-proofing process can be taken: actually carrying out or *implementing the road treatment*. Storm-proofing includes either decommissioning the road, or upgrading and maintaining it.

Road Maintenance

If personnel and resources cannot be committed to providing regular inspection and maintenance for the life of the road, then roads should be built—or rebuilt—as temporary and then properly decommissioned. This is the rule that should be followed if long term fisheries protection is to be achieved. In other words, if the landowner cannot afford to maintain a road, then it should not be put there in the first place. Road maintenance activities include inspections and preventive maintenance, such as winterizing. This includes storm inspections, emergency maintenance, and identifying and treating problem culverts. For large landowners, the maintenance process can be greatly improved by developing a culvert coding or rating system, so it is easy to determine which culverts are most likely to cause erosion problems and which will most likely require storm-period inspection and maintenance.

DEVELOPING COST ESTIMATES

Data Needed for First-Approximation Cost Estimates

Road Upgrading and Decommissioning

For road decommissioning and upgrading, the data that are generally available are photographs and maps based on digital topographic data. Air photographs are also sometimes available, and are very useful for developing estimates of road density and stream-crossing density. After reviewing the photographic and geographic data for an area, you can look for cost data from recently completed upgrading and decommissioning projects that were undertaken in similar geologic and geomorphic terrain. Those cost data are invaluable for making first-approximation estimates on a watershed-wide basis. For example, decommissioning roads across steep inner gorge slopes with high stream-crossing frequencies may cost around $50,000 per mile. In contrast, working on ridge roads or roads in upper hillslope areas of a watershed may only cost $5,000–$10,000 per mile. Knowing where the proposed project is located in the landscape of the watershed, and the associated road and stream crossing densities, will allow you to develop first-order approximations of storm-proofing costs.

Road Maintenance

Developing cost estimates for road maintenance requires data from the same sources as mentioned above. In addition, it is important to know the characteristics of the road surface and the age of the road. From these data, we are able to generate cost estimates, based on the costs of earlier or nearby projects, in much the same manner as for road upgrading and decommissioning storm-proofing projects.

Data Needed for Estimating Cost Categories

Heavy Equipment

In order to develop reasonable cost estimates for heavy equipment work in both road upgrading and road decommissioning projects, it is important to know excavation volumes. Excavation is perhaps the single most expensive work task in many storm-proofing projects. For the first approximation, cost estimates may be based on the number of stream crossings and the average volume per crossing. After doing field reconnaissance inventories, we put each stream crossing in one of several volumetric ranges (e.g., <100 cubic yards, 100–500 cubic yards, or >500 cubic yards). A detailed quantitative survey on an inventoried road system will provide the actual volume of sediment that will be excavated.

It is also critical to know the production rate for the heavy equipment that will be performing the earth moving. The Caterpillar production performance handbook contains exact rates. Another way to obtain production rates is to simply watch heavy equipment excavating stream crossings, excavating unstable fills, and installing or constructing other erosion control and erosion prevention measures (e.g., rolling dips or road outsloping). Production rates are then developed by averaging the observed volumes of sediment excavated or the rates of “installation” for each category of work that is completed. We have developed a standard list of production rates that field inventory personnel employ in conducting inventories and developing cost-estimates for proposed treatments. As a result, all field personnel apply a standard work rate for each task when developing plans for work at new sites.

End-hauling volumes and distances also need to be included in heavy equipment cost estimates, as they can dramatically affect project costs. Even during the driest part of the summer, 40% (or more) of the material excavated from a site (such as an upgraded stream crossing) may not be suitable for reuse at the site and must be end-hauled.

Finally, there are a number of other activities that need to be estimated and added to the project costs. For example, equipment mobilization, road opening costs (for abandoned roads), the installation of general road surface drainage improvements, technical oversight or supervision of the equipment, and overhead costs necessary to manage each equipment subcontract. These costs are all important to take into consideration when developing estimates of project costs.

Labor

To determine or predict labor costs for a proposed project, the amount of time needed to complete each task is calculated. For example, installing a downspout on a culvert will be allocated a given number of hours for a 20-foot downspout of a certain diameter and a greater number of hours for attaching a 30-foot downspout of the same diameter. These time estimates are based on typical efforts – amounts of time taken to complete similar tasks on previous projects. For road upgrading projects, labor is typically employed for a variety of stream crossing installation tasks (bolting culverts, adding downspouts, installing trash barriers or flared inlets, etc.), as well as for mulching, seeding and planting of bare soil areas. Some projects involving bio-technical treatments or gully control measures may be largely installed by hand labor. For road decommissioning projects, most labor is for mulching, seeding and planting activities. From the estimates of time needed for each task, cost estimates for each site and for the project as a whole are calculated using the current labor hourly pay rates for the area of the project. Hourly rates can vary significantly from region to region.

Materials

Material costs are also based on costs for completed projects of similar types, and from established cost lists from suppliers and manufacturers. We use the typical amounts of materials needed for each task, for example, 50 foot long 18 inch diameter pipe for ditch relief culverts, or 40 to 100 feet of 36 inch diameter stream crossing culverts. Materials estimates must take into account design criteria, such as the size of the culvert needed to fit the drainage area and peak discharge for a 100-year flow. Other materials might include bands for connecting culverts, flared inlets, road and rip rap sized rock, seed, plants and straw mulch.

Controls on Costs

Figure 2 contains a list of factors that can impact the costs of road upgrading, decommissioning, and maintenance. These factors must always be taken into consideration when developing cost estimates.

Figure 2. Controls on costs

- Maintenance status of road (open or abandoned/overgrown or washed out)
- Type of road (commercial, ranch, residential, public, etc)
- Inventory, prescription and layout costs
- Assessment and prescription "accuracy" (experience of personnel)
- Heavy equipment and laborer experience in comparable work
- Storm-proofing design specifications
- Stream crossing design standards
- Secondary erosion control treatments "required" (e.g. channel or fill slope armoring)
- Equipment availability and equipment used
- Equipment rental rates (including operator and fuel)
- Surfacing requirements and availability (costs for rock or paving)
- Site frequency
- Stream crossing frequency
- Connectivity of road surface with stream channels
- Supervision requirements
- Site volume (volume excavated)
- Endhaul volume
- Endhaul distance
- Layout requirements (staking or descriptive specifications)
- Contracting method (hourly or bid)
- Overhead

Road Upgrading and Decommissioning

An important factor controlling the difficulty and cost of a project is the status of the road: whether it is currently open or abandoned, and if it is abandoned, whether it is overgrown or washed out at one or more locations. The road status directly affects the access costs for the project. If, for example, the road to be decommissioned is washed out, it will be necessary to rebuild stream crossings and landslides simply to get the equipment to the project work site. During the course of a decommissioning project, equipment will eventually need to remove (excavate) the stream crossings that were just rebuilt. In that case, a washed-out or overgrown road that has been abandoned for some time may cost considerably more to decommission than an open, maintained road that can be driven to the end of the project site. We have developed good cost estimates that predict how much work effort (equipment time) it will take to reopen a road, and how much it will cost per mile to treat roads that fall into each of these different categories (washed out, overgrown, open).

Inventory, prescription, and project layout complexities also are important determinants of project costs. The State of California has a set a standard cost limit for road erosion inventories and erosion prevention planning. The CDFG's Fishery Restoration Grant Program has set an upper limit of about $1,200 per mile for full inventory and assessment, and the development of prescriptions for erosion control and erosion prevention plans for road systems.

The experience and skill of the personnel carrying out the inventory, assessment and project planning are critical factors in determining the final project cost. Good (accurate) inventories are absolutely necessary for the development of cost-effective projects. Equipment operator expertise in implementing the prescriptions is similarly important, and inexperience can greatly increase costs or decrease project cost-effectiveness.

Another control on project cost is whether or not secondary erosion control treatments are required. Secondary erosion control treatments are those designed to control or prevention erosion on bare soils that were exposed as a result of the main storm-proofing treatment. If for example, after a stream crossing has been excavated on a decommissioned road, the channel bed and bank needs to be armored to prevent down cutting or bank erosion, the project costs will be considerably higher than if no such treatment is required. In many cases, the secondary erosion control treatments are very expensive to apply, and these costs do not necessarily translate into proportionately more sediment prevented from entering the stream. Secondary erosion control is often not as cost-effective as the primary road treatment measures (Weaver and Sonnevil, 1984).

Equipment availability, types of equipment used, and rates charged for equipment rental and operation are factors that directly affect project costs. Equipment rates can vary considerably from region to region, often mirroring general cost-of-living expenses in the local communities or nearby cities. For example, rental rates for the same hydraulic excavator can vary as much as 60% between rural northern California and the San Francisco Bay area. Similarly, the proximity of materials and supplies for the road work is a key cost determinant. If, for example, you are replacing stream crossings on a rock surfaced or paved road, the road will need to be re-surfaced as a part of the treatment. If rock must be brought in from 10 miles away, it will be much more expensive than if the rock can be obtained locally.

Working on paved public roads has proven to be highly costly. Public road departments typically provide increased engineering as compared to private roads, and this added design step increases costs. In addition, public roads require a suite of different prescriptions than do private roads. For example, public roads require a variety of safety designs that exclude the use of such road surface drainage features as rolling dips. Alternate designs are often required. Work on public roads also requires the use of additional safety measures, such as traffic control, that can add substantially to project costs. Finally, costs associated with extra endhauling of spoils, re-paving, striping, installing guard rails and other measures can make the same storm-proofing project cost up to three times more than comparable projects on private land road systems.

The physical characteristics of the road network under consideration will also have a significant impact on project cost. The density of roads in the area, the frequency with which stream crossings occur, and the connectivity of the road surfaces with stream channels all must be taken into consideration. More roads will likely mean more work to be done, as will a higher frequency of stream crossings. How connected the road surface is to the stream channel network will dictate the number of ditch relief culverts, rolling dips, or miles of road reshaping work that must be completed. Costs will generally increase with higher levels of road/stream connectivity.

Supervision requirements, volume of fill to be excavated at the site, and end-haul volumes are all important considerations. Layout requirements at the site are also factors: whether you will have to stake the site or simply provide prescriptive specifications. Contracting methods make a difference, depending on whether you employ an hourly contract or you utilize a minimum or least-cost bid. Overhead costs vary between agencies and contractors and can thus have some impact on the final project cost.

A final issue is that of staging: having materials and equipment on site at the right time in order to maximize project and cost efficiency. For example, in working with a large industrial landowner in Northern California, road upgrading work was given a lower priority than logging operations. This meant that whenever equipment was needed for logging, it could not be used for the road work for 3 or 4 days, leaving the equipment operator with little to do until the missing equipment was returned (in this case, dump trucks). In the end, a storm-proofing project that was originally predicted to cost about $45,000 per mile ended up costing over twice as much.

Road Maintenance

Road maintenance costs depend primarily on road length and road density; these often determine the scope of the job and the maintenance status of the road. Maintenance costs are also affected by the age of the road, which might be new, developed, or seasoned. Maintenance costs for a road that has been upgraded and storm-proofed can be expected to be much lower than for one that is underdesigned, poorly constructed or in significant disrepair.

The stream crossing frequency along a road often has a large impact on the level of maintenance required. Ridge-top roads, which have many fewer stream crossings than riparian roads, generally require less maintenance than riparian roads. Similarly, poorly drained roads, regardless of their location, often require regular maintenance to keep them in a passable condition. Another important factor determining maintenance costs is the value of the resources near the stream, because maintenance will of necessity be much more complex and of greater importance along roads that impact streams with very sensitive resources.

Finally, there exist many different interpretations of what constitutes appropriate and complete maintenance. The standards that can be applied to road maintenance are many. The standards that are eventually adopted in a given project area can greatly affect the cost to do the work, with more rigorous standards demanding higher costs for implementation. For example, if a culvert plugs every year, is it proper to simply clean it out each year, or does the culvert need to be upgraded as a part of the routine maintenance operation? These two treatment options clearly involve very different implementation costs.

Refining Cost Estimates

For a first approximation of storm-proofing and road maintenance costs, it is fine to rely on existing cost data for similar work in similar terrain. Refining the first approximation requires a site-by-site analysis of project costs at the reconnaissance level and a detailed quantitative inventory (see above).

At the reconnaissance level, more detailed cost estimates are based on the frequency of stream crossings in the road system, the sediment volume ranges at each of the crossings, the potential for fillslope failure, the estimated lengths of ditches to be disconnected from the system, the various drainage structures to be installed, and the estimated end-hauling requirements for the road system.

In order to obtain a final detailed cost estimate, it is necessary to visit the sites and tailor the costs to each individual site. This is information that is provided in a quantitative inventory and assessment of the road or road network.

The final complications in determining project costs are often the result of the different definitions of road treatments that are applied by different people. It makes it difficult to aggregate and compare costs between projects if people do not employ the same definitions of effective road treatments. For example, while road decommissioning means excavating stream crossing fills down to the original streambed to some people (so that post-treatment downcutting will not occur), to others it may mean simply removing the culvert pipe and leaving most of the fill in the streambed. Clearly, these two different implementation standards will have very different costs and outcomes associated with them. Standardized definitions and treatment prescriptions, and detailed project objectives, are marks of effective erosion prevention and erosion control projects.

ESTIMATING COSTS FOR LARGE-SCALE PROJECTS

Cost Variation

Unit costs often decrease with the scale of the project (economy of scale). However, costs are very dependent on the types of work included in a project. For example, if an entire watershed transportation system is included in a project, the average cost per mile of road treated will drop dramatically as compared to a project that proposes to treat only the highest priority sites, or a small sample of all the possible sites. This is because you are including high priority sites, moderate priority sites, and low priority ridge top roads. The ridge top roads have very low stream crossing frequencies and as a consequence may not have as much work that needs to be done. The average amount spent per mile may be around \$15,000–\$20,000. In contrast, if the project only includes the high priority sites, the average unit cost may be \$50,000–\$60,000/mile. It is thus very important to know what “types” of roads have been included in a project when comparing costs between your proposed project and other projects that may have been completed in the same general area. The nature and location of project work in a watershed can have a significant effect on cost.

In some cases, it is possible to take advantage of discounts on material orders for larger scale restoration efforts. When purchasing culverts, for example, a single 20 foot, 24 inch standard culvert is relatively more expensive than a mile of culvert from the same vendor. The price may decrease by 20% to 25% when the order is increased to comparatively large amounts of materials or supplies.

Larger projects may also have reduced mobilization costs compared to smaller projects. The heavy equipment will only have to be brought to the area once, and can be moved around within the watershed as the project progresses without need of the expensive mobilization equipment.

Finally, there will be a cost reduction associated with increased operator experience and the development of a large pool of experienced operators. Two of the most important determinants of the cost of both road upgrading and road decommissioning projects are the skill and experience of the operators. With a large-scale restoration effort, an opportunity exists to develop a large group of skilled operators, which can lead to greatly reduced project costs. In addition, each individual contractor will give much better hourly rates for large jobs, because of the increased job security. A contractor may charge $125 an hour to decommission a mile of road, but if the contract will last the entire summer, the rate may drop to $100 an hour.

Changes in Information Requirements

Researching and properly preparing all of the information needed for restoration project planning changes very little as the size of the project increases. It is still necessary to have the same ground-based information, on a site-by-site basis, that will allow you to effectively prescribe the individual road treatments and predict costs.

It is important, though, to employ standardized inventory and prescription tools and protocols, developing "intelligent uniformity" in the way that the project prescriptions are developed and laid out. Just as the skill of the operators can make a big difference in the work on the ground, the people who are planning and prescribing the work have an even more fundamental role in determining what work is done and how much it costs. The skill and experience of the people doing the inventory and laying out the work plan are critically important in keeping costs down and maintaining cost-effectiveness.

In order to ensure that skill standards are employed and followed on a project, it is very useful to require that the inventory personnel and the equipment operators have all been thoroughly trained and have been through a standardized training assessment. This will lead to the development of consistent and repeatable results on the ground. In any long-term restoration program, uniformity, consistency, and repeatability are critical to the success and cost-effectiveness of a storm-proofing project.

Developing the Feedback Loop

Our work is all adaptive restoration, which means that we monitor and document the work that is being performed. It is important to require operators to record and report how much time and effort is spent on each work site. As a result, your ability to estimate the cost and time required to complete a work task or a complete project element will improve over time. You will also be able to clearly recognize when inefficient or ineffective inventory personnel, equipment operators or laborers are adversely affecting restoration effectiveness or cost-effectiveness.

Large-Scale Data Sources and Availability

If a project is to be planned on a large scale, it is crucial to have access to data sources that encompass the entire area under consideration. The quality and complexity of these sources can vary widely. Road network maps available for the project might include GIS maps from a large timber company, the county, or the state. You might also rely on USGS topographic maps, orthophotos or Digital Elevation Models of the project area that can then be converted into project maps.

Experience has demonstrated that anywhere from 15% to 50%, or more, of the roads in a forested landscape are not shown on existing maps, depending on the land ownership in the area. We have dealt with some timber companies that have put literally 90% of their roads on their maps, and others that have mapped only 50% of the roads built in the watershed. Some companies have not mapped their roads at all. Even in the U.S. Forest Service, the general custom is to show on maps the roads that are currently open and maintained and to omit the roads that are not maintained, those abandoned 20 to 30 years ago and since overgrown with vegetation. Both used and unused roads represent potential sediment sources, and ought to be identified on maps and inventoried in the field.

Road maps are typically unavailable for small landowners, unless they have been actively involved in resource extraction (such as timber harvesting). Landowners that have less than 5000 acres are not likely to have GIS systems; at most, they will have a paper map of their roads. Road maps for small landowners are usually difficult to obtain, unless there has been a level 1 air-photograph analysis of the watershed through time. If that is available, you can track and identify all the roads that have ever been constructed in the watershed.

Digital topography is available and can be useful for determining approximate stream-crossing frequencies, which is one of the key elements in estimating the cost of a project. Road construction history is generally not available, but it can be useful for determining road status: which roads are abandoned and which roads are maintained. It is possible to look at the most recent aerial photographs and see the roads that are being used. However, there will always be roads that are hidden beneath the vegetation, especially in coastal areas. Some of the road network may be open and driveable, but still invisible in the most recent aerial photography.

In addition to geographic data, it is also important to make use of large-scale data sets regarding local contractors and equipment rates. These are necessary for cost estimating, and are generally readily available from the private sector. Phone calls and solicitations for non-specific equipment bids will quickly generate hourly cost rates for a variety of equipment types and project areas. The same "bids" can be used to identify those contractors with appropriate equipment for road storm-proofing, as well as those contractors with relevant past experience on similar projects.

Developing Cost Estimates from Level 3 Field Inventory Data

Level 3 field inventories are for fifth-field watersheds. Developing costs at the watershed level involves the completion of nine different steps, which are listed in Figure 3. First the sites to be treated must be identified. Sites are defined as features that are likely to deliver sediment to a stream channel in excess of a given number of cubic yards. This threshold level of sediment delivery is typically set anywhere from 10 to 50

Figure 3. Developing cost estimates from Level 3 field inventory[1] data

1. Problem identification (depends on the volumetric definition of a "site")
2. Problem quantification (volume measurements and calculations)
3. Determine equipment needs (desired capabilities and types)
4. Estimate production rates and equipment times
5. Estimate equipment costs, with logistic multiplier (30%) for prescribed treatments, by site
6. Estimate road opening costs (dependent on maintenance status and re-vegetation)
7. Estimate mobilization costs (dependent on equipment needs and availability)
8. Calculate material costs (culverts – for upgrading, seed, mulch, etc.)
9. Calculate labor costs (mostly for culvert installation, planting and mulching)

1- Costs for field inventory and preparation of implementation plan: $800–$1,200/mile, or less

Table 4. Sample techniques and costs for decommissioning and upgrading rural roads

Treatment	Typical use or application	General costs1
DECOMMISSIONING TREATMENTS		
Ripping or decompaction	Improve infiltration; decrease runoff; assist re-vegetation	\$500–\$1600/mile
Construction of cross-road drains	Drain springs; drain insloped roads; drain landings	\$1/ft (\$25–\$50 ea)
Partial outsloping (local spoil site; fill against the cutbank)	Remove minor unstable fills; diverse cutbank seeps and runoff	\$1/yd^3; \$2500–\$9500/mile
Complete outsloping (local spoil site; fill against the cutbank)	Used for removing unstable fill material where nearby cutbank is dry and stable	Averages \$10,000+/mile (\$1/yd^3)
Exported outsloping (fill pushed away and stored down-road)	Used for removing unstable road fills where cutbanks have springs and cannot be buried	\$1–\$4/yd^3, depending on push distance
Landing excavations (with local spoil storage)	Used to remove unstable material around landing perimeter	\$1–\$2/yd^3, high organics can increase costs
Stream crossing excavations (with local spoil storage)	Complete removal of stream crossing fills (not just culvert removal)	Averages \$1.50–\$3.50/yd^3, but can vary considerably
Truck endhauling (dump truck)	Hauling excavated spoil to stable, permanent storage location where it will not discharge to a stream	\$3–\$5/yd^3 on top of basic excavation work
UPGRADING TREATMENTS		
Outslope road and fill ditch	Converting and insloped, ditched road to an outsloped road to disperse road runoff	\$170/1000 feet
Rolling dip	Constructed to drain the road surface and, if deep enough, the ditch	\$85 each
Rock road surface	Surface road using 1.5″ to 2.0″ crushed rock	\$4,250/1000 feet
Install ditch relief culvert	Culvert installation to improve dispersion of road and ditch drainage	\$550–\$650 each

Table 4. Sample techniques and costs for decommissioning and upgrading rural roads (cont'd.)

Stream crossing upgrade	Culvert installation or replacement (in this case 36″ x 40′ in a 200 cu yd fill)	$2,445 each
Straw mulch	Mulch bare soil areas with 3000 lb/acre straw	$13/1000 sq ft
Costs are variable depending on material costs, equipment types and rates and operator experience.		

1- These are direct treatment costs for equipment working at a site. They do not include transportation, moving from site-to-site, overhead, supervision, layout, or any other costs. Costs will vary for site to site and from watershed to watershed. Heavy equipment treatments performed using D-6 and D-7 size tractors and hydraulic excavators with average 2 yd^3 bucket size. Data from PWA and NPS, Redwood National Park (1992).

cubic yards per site. Less than the threshold, and the site is not inventoried or is inventoried at a reduced level.

Next, the problems to be treated at the selected sites are inventoried and quantified. This involves measuring the volume (cubic yards) of sediment that will be delivered to the stream system if the roads are left untreated. Next, determine which types of equipment will be needed to do the work that has been prescribed. This typically includes excavators, bulldozers, and dump trucks for road decommissioning. In addition to these, water trucks, graders, rollers and other equipment are often employed on road upgrading projects. Production rates are estimated based on the site characteristics and the complexity of individual work sites. For example, we calculate how many cubic yards can be excavated in an hour based on the limiting piece of equipment, which is usually the excavator. In excavating a large, deep stream crossing containing abundant organic debris (logs), you might apply an excavation rate of 35 to 45 cubic yards per hour for an excavator with a 2 cubic yard bucket. On the other hand, if the stream crossing is small and less complex, the work may be completed at a rate of 85 to 100 cubic yards an hour.

Other factors determining the project cost include the time needed to move the equipment between sites, the costs for opening abandoned roads so that equipment can be brought in to the most remote work sites, and the time and costs required to seed and mulch the site after the upgrading or decommissioning work is complete.

We have developed a set of standardized unit costs for different types of treatments. These are described in Table 4. The list includes many of the common practices used in upgrading, decommissioning and maintaining roads. We apply these standard costs in the field when developing initial cost estimates. Based on years of experience, the standards are a reliable method for approaching a first cost approximation.

In the field, costs are developed using a spreadsheet similar to the one shown in Table 5. The spreadsheet contains all of the major cost categories associated with a project, which include moving the equipment in and out of the site, road opening costs, heavy equipment requirements for treating all the sites, heavy equipment requirements for disconnecting the road surface drainage from the stream channel, labor costs, culvert costs, re-vegetation costs and project technical supervision. Each one of these categories is supported by a separate spreadsheet used to calculate individual costs in detail. After determining the project costs, the total future sediment delivery prevented by the project can be calculated, as can the cost effectiveness of the project ($/$yd^3$ of sediment prevented from being delivered to the stream system).

Table 5 is an example of a completed cost spreadsheet for high or high to moderate priority sites in a watershed. In this particular road system, the total cost for completing all storm-proofing work in the watershed was calculated to be $730,000. We calculated that for this project, we were preventing a future sediment yield of approximately 62,000 cubic yards. The cost effectiveness was about $12 per cubic yard for the average road.

Table 5. Cost worksheet for high and high/moderate sites

Cost category	Equipment	Cost rate ($/hr)	Treatment (hrs)	Logistics (hrs)	Total (hrs)	Total estimated costs ($)
Move in/out (Lowboy)	Excavator	95	4	NA	4	380
	Dozer	70	4	NA	4	280
Road opening costs	Excavator	115	213	NA	213	24,495
	Dozer	85	213	NA	213	18,105
Heavy equipment requirements for site specific treatments	Excavator	115	1479	444	1923	221,111
	Dozer	85	1534	460	1994	169,507
	Dump truck	60	425	128	553	33,150
	Backhoe	65	0	0	0	0
	Grader	85	0	0	0	0
Heavy equipment requirements for road drainage treatment	Excavator	115	18	5	23	2,691
	Dozer	85	336	101	437	37,128
	Backhoe	65	0	0	0	0
	Grader	85	24	7	31	2,652
Laborers		20	740	22	962	19,240
Rock costs						43,601
Culvert costs						115,346
Mulch, seed costs						6,952
Layout, coordination		50	NA	NA	728	36,387
Total estimated costs						730,484
Future yield (yds^3) (includes chronic road surface erosion and sediment delivery)						61,192
Cost-effectiveness ($/$yds^3$)						11.94

Using standardized spreadsheets and lists of previous costs for different types of work can greatly help to streamline the cost estimation procedure. These devices also help to ensure that cost estimates for erosion prevention and erosion control work associated with road storm-proofing remain consistent over both time and geographic area. This helps maintain highly consistent and accurate work standards and cost-effectiveness.

To quantitatively determine whether it is possible to make predictions about project costs based on site characteristics, we did an analysis where we compared a number of different parameters for five watersheds. The total length of road in those watersheds or watershed assessment areas was 328 miles. Furthermore, the calculations were only based on high and moderate priority sites, not the low priority sites.

The costs for implementing these road decommissioning projects ranged from \$10,500 to \$30,500 per mile. We were able to achieve a reasonable prediction of cost based on the number of sites per mile, which ranged from 2.8 to 9.3. The best predictor of cost, though, was the measure of future volume (cubic yards) of sediment prevented from entering the stream within the project boundary. Our study demonstrated that it is possible to get a rough idea of how much a project is ultimately going to cost based on the amount of sediment saved by that project, and the density of treatment sites.

Table 6 has decommissioning unit costs per mile for five different watersheds, which contain 27 miles of decommissioned road. Our unit costs for this work ranged from \$25,800 to \$77,400 per mile. The difference in costs is primarily a function of the number of sites (site density), which ran from a low of about 8 sites per mile to a high of about 25 sites per mile. In addition, the unit volumes of material that needed to be excavated from the stream crossings in order to decommission the roads, ranged from about 3,500 to 10,000 cubic yards per mile. Both the site density and the amount of fill to be exca-

Table 6. Analysis of data from five road decommissioning proposals, Northern California watersheds (1998 and 2000)

Project	Total cost (\$)	Road length (mi)	Sites (#)	Excavated volume (yd³)	Unit cost/mile (\$/mi)	Unit cost/vol (\$/yd³)	Site density (#/mi)	Unit vol/mile (yd³/mi)	Unit vol/site (yd³/site)
Rowdy Creek 1999	134,245	5.2	41	18,500	25,820	7.25	7.9	3,560	451
Salmon Creek 1998	304,790	7.3	61	44,000	41,750	6.92	8.4	6,030	733
Rowdy Creek 2000	374,876	6.3	53	42,000	59,500	8.93	8.4	6,670	792
Redwood Creek 2000	290,461	4.5	57	36,000	64,550	8.06	12.7	8,000	632
Little River 2000	301,936	3.9	100	42,000	77,420	7.19	25.6	10,770	420
Totals	**1,406,308**	**27.2**	**312**	**182,503**	**51,700**	**7.71**	**11.5**	**6,710**	**585**

Table 7. Typical road upgrading and road decommissioning costs

Road upgrading[1] (difficult roads; 100-year design)	$42,500/mile
Road upgrading[2] (moderate to difficult roads with high site density)	$45,500/mile
Road upgrading[3] (watershed-wide, low & high priority roads; 100-year design)	$25,000–$35,000/mile
Road upgrading[4] (watershed-wide average; 100-year design)	$10,000–$35,000/mile
Road decommissioning[5] (moderately difficult roads)	$51,000/mile
Road decommissioning (range of roads – ridge spurs to moderate complexity)	$2,000–$35,000/mile

1- Based on 20 miles of actual costs for treatment of high priority road reaches; with mix of about 20% decommissioning and 80% upgrading.
2- Based on detailed field inventory and cost estimate for 19 miles of road.
3- Estimates based on approximately 160 miles of "storm-proofed" road.
4- Based on mix of road types from 328 miles of inventoried forest roads, including a range of high priority (streamside) to low priority (ridge) road systems in 5 watersheds. Includes both upgrading and decommission road reaches.
5- Based on detailed inventories and cost estimates for 27 miles of road decommissioning.

vated can be good indicators of project cost. Unfortunately, predictions of this kind require some fieldwork in order to quantify site densities and amounts of fill to be excavated on a watershed level scale. Some of this landscape level information is predictable, based primarily on data other people have collected in similar watersheds or similar terrain, but in most cases there is no substitute for surveying the area directly.

Typical Costs

Road Upgrading and Decommissioning

Table 7 provides a list of typical project costs, based on six general categories of road upgrading and road decommissioning on non-public, unpaved road systems. These costs have been obtained from storm-proofing work completed or in-progress. The costs have been extracted from inventories, estimates, and completed project cost totals. The averages here are representative of a range of different projects, and so provide a general perspective on the costs that can be expected for various types of projects. Considerable variability can be expected and paved public roads will be significantly more expensive.

Upgrading difficult roads with a 100-year design standard has averaged $42,500 per mile. This average is based on 20 miles of upgrading work completed in 1999 and includes all stream crossing upgrades, road surfacing, and excavation and removal of unstable fill slopes with a potential for future sediment delivery.

The second item, road upgrading at moderate to difficult sites with a high site density, is an estimate based on 19 miles of road. The average amount spent on these projects was $45,500. Our definition of difficult roads includes roads built in the riparian zone and steep stream-side slopes. These roads were built on steep slopes probably in the 1940s or 1950s. In some cases the roads are old railroad grades that have been since converted to truck roads. Riparian roads are very close to the stream, and the potential for sediment delivery to the stream from any failures is high. The combination of difficult riparian roads with the very high site density of these projects results in costs that are at the high end of what one would expect in the average North Coast watershed.

If the cost estimate is expanded to include an entire watershed, which in this case is about 40 square miles, the unit costs for upgrading or decommissioning virtually all the roads in the watershed would probably be about $20,000 to $25,000/mile. When working on all of the roads in a watershed, the work will not necessarily be spread out evenly: the watershed will be prioritized and in so doing, the places most likely to fail and most likely to deliver sediment to the streams are selected first. As a result, the sites that are selected and completed in the first two years are going to be the most expensive sites. They will also be the most time consuming sites. However, even though this means that only a few miles will be treated, there will be a big reduction in the volume of, and potential for, future sediment delivery.

The third item is an average cost for upgrading roads in an entire watershed, including both high and low priority roads and employing a 100-year design standard. The cost is $25,000–35,000 per mile, based on 160 miles of storm-proofing completed on land owned by an industrial timber company. The estimate includes a wide range of types of road, from ridge roads (which has few crossings and is relatively easy to treat) to riparian roads (which have many crossings and are difficult to access and work on).

The fourth estimate is for road upgrading on a watershed scale, with 100-year design standards. It is based on a mix of road types across 328 miles of road inventoried on another industrial timberland owner. The estimate is similar to that in item 3, since both are on the watershed level and include a variety of road types and locations.

An average cost for road decommissioning is listed as the fifth item. The decommissioning in this case is on roads with moderately difficult sites, and is based on detailed inventories for 27 miles of completed project work. If the work is done in an efficient manner, the cost may be around $51,000 per mile. In the sixth and final cost figure, the average cost for road decommissioning individual forest and ranch roads is listed as $2,000 to 35,000 per mile. This is for a range of roads and sites on the entire watershed level and thus includes all levels of difficulty. Depending on site densities and locations of the road (ridge, riparian, mid-elevation), the cost can vary considerably.

Road Maintenance

Typical maintenance inspection costs for forest road systems are approximately $25 per mile per year. This includes a full annual inspection of all roads, stream crossings and fill slopes that are showing signs of potential instability. It also includes intermittent winter storm maintenance inspections and inspection during and following major storm events. Road maintenance is separate from any timber harvest-related activity and separate from a storm-proofing program where the roads are actually upgraded. Maintenance just means keeping the roads at minimal level of stability, so they do not decompose and the culverts do not plug and wash out. Routine culvert replacement, culvert cleaning, and fill slope excavations (where needed) can cost about $275/mile per year. This higher cost is based on roads that are actually failing and need to have immediate maintenance measures taken to prevent more catastrophic failure. These costs are from an industrial forest landowner with over 3,000 miles of forest roads.

Maintenance costs can be difficult to calculate, though, because the standard costs calculated for the work can vary between different groups and different projects. For example, publicly maintained county roads will have a significantly different set of cost figures from those of a large industrial landowner. Rural subdivisions will have another set of inspection and maintenance costs. It is best to base cost estimates on as many different sources of comparable situations as possible.

EVALUATING COST ESTIMATES

Confidence in Watershed/ESU Cost Estimates

Cost estimate reliability is dependent upon the level of the estimate, and whether it is a preliminary first-approximation or the result of a detailed estimating procedure. Confidence in an estimate also depends on data availability and the quality of the data. Typically there is not much data available for a given project location, and the quality of the estimate is fair to poor. We have completed extensive inventories in Northern California covering over 1,000 square miles of land, a large area from which to compile cost data and multiple cost-estimates.

Confidence in cost-estimating is greatly increased by employing real data from road upgrading and road decommissioning projects. Generally, as the project area increases, the confidence level for estimates of the costs to do work in that area decreases. The greatest confidence in cost estimates for road storm-proofing is achieved for projects that have detailed quantitative inventories and assessments of problems sites (together with specific prescriptions for erosion prevention and erosion control work, including heavy equipment and labor needs, and material costs), and project cost data for similar work actually completed in the local area.

CONCLUSION

When estimating the costs of road upgrading, decommissioning and maintenance, it is important to understand that generalizations and extrapolations of similar cost data can only go so far. In the end there is no simple way around the need for detailed surveys of the area under consideration for upgrading, decommissioning or maintenance. Road surveys and quantitative inventories are crucial first steps in planning and developing cost estimates for new road treatment projects. Standardized methods for conducting sediment source inventories and for developing project costs can help maintain consistency between projects and creating a body of data that can be used as a reliable base from which to develop new projects. We have found that there are some site characteristics that can be used as reliable predictors of project cost, in particular the future sediment yield prevented by the project. Correlations such as this can only be made based on years of experience in the field, but they can be very valuable tools for developing new projects.

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